

Quick Review From Last Video:

The Capacitor

Two Conductive Plates Separated by an Insulator (Dielectric)

Positive Plate
Stores positive charge (+Q)

Negative Plate
Stores negative charge (-Q)

Dielectric (Insulator)

Conductive Plate

Electric Field
(From + Plate to - Plate)

Capacitance
 $C = Q/V$

Where:
 C = Capacitance (farads)
 Q = Charge on plates (coulombs)
 V = Voltage across plates (volts)

How It Works
When a voltage is applied across the plates, equal and opposite charges build up on the plates. The dielectric (insulator) prevents the charges from flowing to each other, allowing the capacitor to store energy in the electric field between the plates.

Key Points
 • Two conductive plates separated by a dielectric.
 • Stores energy in an electric field.
 • Measured in farads (F).
 • Used for filtering, timing, coupling, decoupling, and energy storage.

Common Symbols
 + || - Non-Polarized
 + | (- Polarized

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What Affects Capacitance?

Capacitance (C) depends on three things:
Plate Area (A), Distance Between Plates (d), and Dielectric (ϵ_r)

Formula:

$$C = \epsilon_r \epsilon_0 \frac{A}{d}$$
 (ϵ_0 = constant)

1 Plate Area (A)
Bigger area = More capacitance

Area = A Area = 2A

$C = C_1$ $C = 2C_1$

Double the area, double the capacitance.

2 Distance Between Plates (d)
Smaller distance = More capacitance

Distance = d Distance = d/2

$C = C_1$ $C = 2C_1$

Cut the distance in half, double the capacitance.

3 Dielectric (ϵ_r)
Better dielectric (higher ϵ_r) = More capacitance

Air ($\epsilon_r = 1$) Plastic ($\epsilon_r = 2$) Ceramic ($\epsilon_r = 1000$)

$C = C_1$ $C = 2C_1$ $C = 1000C_1$

Higher ϵ_r , more capacitance.

In Short:

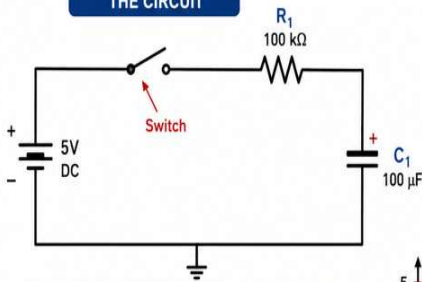
- Bigger plate area (A) → More capacitance
- Smaller distance (d) → More capacitance
- Higher dielectric (ϵ_r) → More capacitance

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PART 1: THE SIMPLE RC CIRCUIT

Charging and Discharging a Capacitor Through a Resistor

THE CIRCUIT

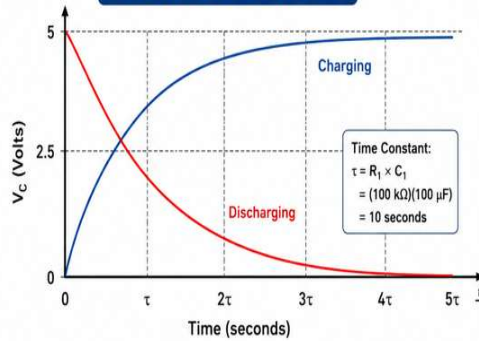


COMPONENTS

- DC Supply (V_S) = 5 V
- Resistor (R_1) = 100 kΩ (100,000 Ω)
- Capacitor (C_1) = 100 μF
- SPST Switch



CAPACITOR VOLTAGE vs. TIME



CHARGING (Switch Closed)

Current flows from the 5V supply through R_1 into C_1 . The capacitor voltage (V_C) rises from 0V toward 5V.

DISCHARGING (Switch Open)

The capacitor discharges through R_1 . The capacitor voltage (V_C) falls from 5V toward 0V.



KEY TAKEAWAY

The capacitor does not charge or discharge instantly. The voltage changes over time, creating exponential curves.

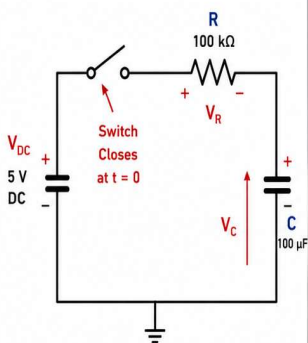
RC Circuit Charging:

We can predict exactly how long it takes for the capacitor to charge:

THE TIME CONSTANT (τ)

It tells us how long it takes a capacitor to charge.

THE RC CIRCUIT (CHARGING)



TIME CONSTANT EQUATION

$$\tau = R \times C$$

Where:
 τ = time constant (seconds).
 R = resistance (ohms)
 C = capacitance (farads)

EXAMPLE:

$R = 100 \text{ k}\Omega = 100,000 \Omega$
 $C = 100 \mu\text{F} = 0.0001 \text{ F}$

$$\tau = (100,000)(0.0001)$$

$$\tau = 10 \text{ seconds}$$

WHAT DOES τ MEAN?

After one time constant ($t = \tau$), the capacitor has charged to about 63.2% of its final voltage.

MATHEMATICAL EQUATION (Charging)

$$V_C(t) = V_{DC} (1 - e^{-t/RC})$$

At $t = \tau = RC$:

$$V_C(\tau) = V_{DC} (1 - e^{-1})$$

$$= V_{DC} (1 - 0.3679)$$

$$V_C(\tau) = 0.632 V_{DC}$$

$$0.632 \approx 63.2\%$$

WHY 63%?

Because when $t = \tau$ (or $t = RC$), the exponent is -1.

$$e^{-1} \approx 0.3679$$

$$1 - 0.3679$$

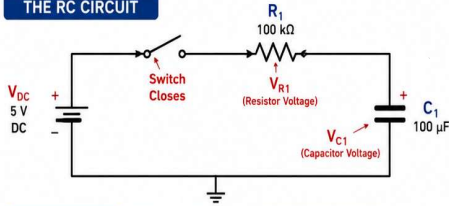
$$= 0.632$$

$$(63.2\%)$$

RC CIRCUIT CHARGING – VOLTAGES & CURRENT OVER TIME

As the capacitor charges, the resistor voltage and current decrease.

THE RC CIRCUIT



KIRCHHOFF'S VOLTAGE LAW (KVL)

At all times during charging:

$$V_{DC} = V_{R1} + V_{C1}$$

OHM'S LAW (CURRENT THROUGH RESISTOR)

$$I = \frac{V_{R1}}{R_1} \quad \text{where } R_1 = 100 \text{ k}\Omega$$

TIME (During Charging)	V_{DC} (Supply Voltage)	V_{R1} (Resistor Voltage)	V_{C1} (Capacitor Voltage)	KVL CHECK $V_{DC} = V_{R1} + V_{C1}$	I_{R1} or I (Current Through R_1) $I = V_{R1} / 100 \text{ k}\Omega$
1. Start ($t = 0$)	5 V	5 V	0 V	$5 = 5 + 0$	$5 / 100 \text{ k}\Omega = 50 \mu\text{A}$
2. Early	5 V	4 V	1 V	$5 = 4 + 1$	$4 / 100 \text{ k}\Omega = 40 \mu\text{A}$
3. Mid	5 V	3 V	2 V	$5 = 3 + 2$	$3 / 100 \text{ k}\Omega = 30 \mu\text{A}$
4. Mid	5 V	2 V	3 V	$5 = 2 + 3$	$2 / 100 \text{ k}\Omega = 20 \mu\text{A}$
5. Late	5 V	1 V	4 V	$5 = 1 + 4$	$1 / 100 \text{ k}\Omega = 10 \mu\text{A}$
6. Fully Charged (Steady State)	5 V	0 V	5 V	$5 = 0 + 5$	$0 / 100 \text{ k}\Omega = 0 \mu\text{A}$ ($\approx 0 \mu\text{A}$)



KEY TAKEAWAYS

- As the capacitor charges, V_{C1} increases.
- As V_{C1} increases, V_{R1} decreases.

- Since $I = V_{R1} / R_1$, the current through the resistor decreases.
- KVL is always true: $V_{DC} = V_{R1} + V_{C1}$ at every instant.

In this example:

$R_1 = 100 \text{ k}\Omega$
 $C_1 = 100 \mu\text{F}$

$$R \times C = 100 \text{ k}\Omega \times 100 \mu\text{F} = 10 \text{ s} = \tau$$

$$V_C = V_{DC} (1 - e^{-\frac{t}{RC}})$$

$$\tau = 10$$

$$\tau = 10 \text{ s} \quad V_C = V_{DC} (1 - e^{-\frac{10}{10}})$$

$$V_C = V_{DC} (1 - e^{-1})$$

$$t = 10 \text{ s}$$

$$t = 1 \text{ s} \quad V_C = V_{DC} (1 - e^{-\frac{1}{10}})$$

$$t = 10 \text{ s} = \tau \quad V_C = 5 (1 - e^{-\frac{1}{10}}) = 0.476 \text{ V}$$

$$t = 1 \text{ s} \rightarrow V_C = 5 (1 - e^{-\frac{1}{10}}) = 0.476 \text{ V}$$

$$\tau = 10 \text{ s} \quad V_C = 5 (1 - e^{-\frac{10}{10}}) = 3.16 \text{ V}$$

side note:

$$I_t = \frac{V_{DC} - V_{C1}}{R_1} = \frac{V_{DC} - V_{DC} (1 - e^{-\frac{t}{RC}})}{R_1} = \frac{V_{DC} - V_{DC} + V_{DC} e^{-\frac{t}{RC}}}{R_1} = \frac{V_{DC} e^{-\frac{t}{RC}}}{R_1}$$

$$V_{R1} = V_{DC} - V_{DC} + (V_{DC} e^{-\frac{t}{RC}})$$

$$V_{R1} = 0 + (V_{DC} e^{-\frac{t}{RC}}) \quad I_1 = \frac{V_{R1}}{R_1}$$

$$I_t = \frac{V_{DC}}{R_1} e^{-\frac{t}{RC}} \quad 1.839 \times 10^{-5}$$

$$\tau = 10 \quad \frac{5 \text{ V}}{100 \text{ k}\Omega} \cdot e^{-\frac{10}{10}} = 18.4 \mu\text{A}$$

$$t = \tau = 10 \text{ s}, \quad I_t = 18.4 \mu\text{A}$$